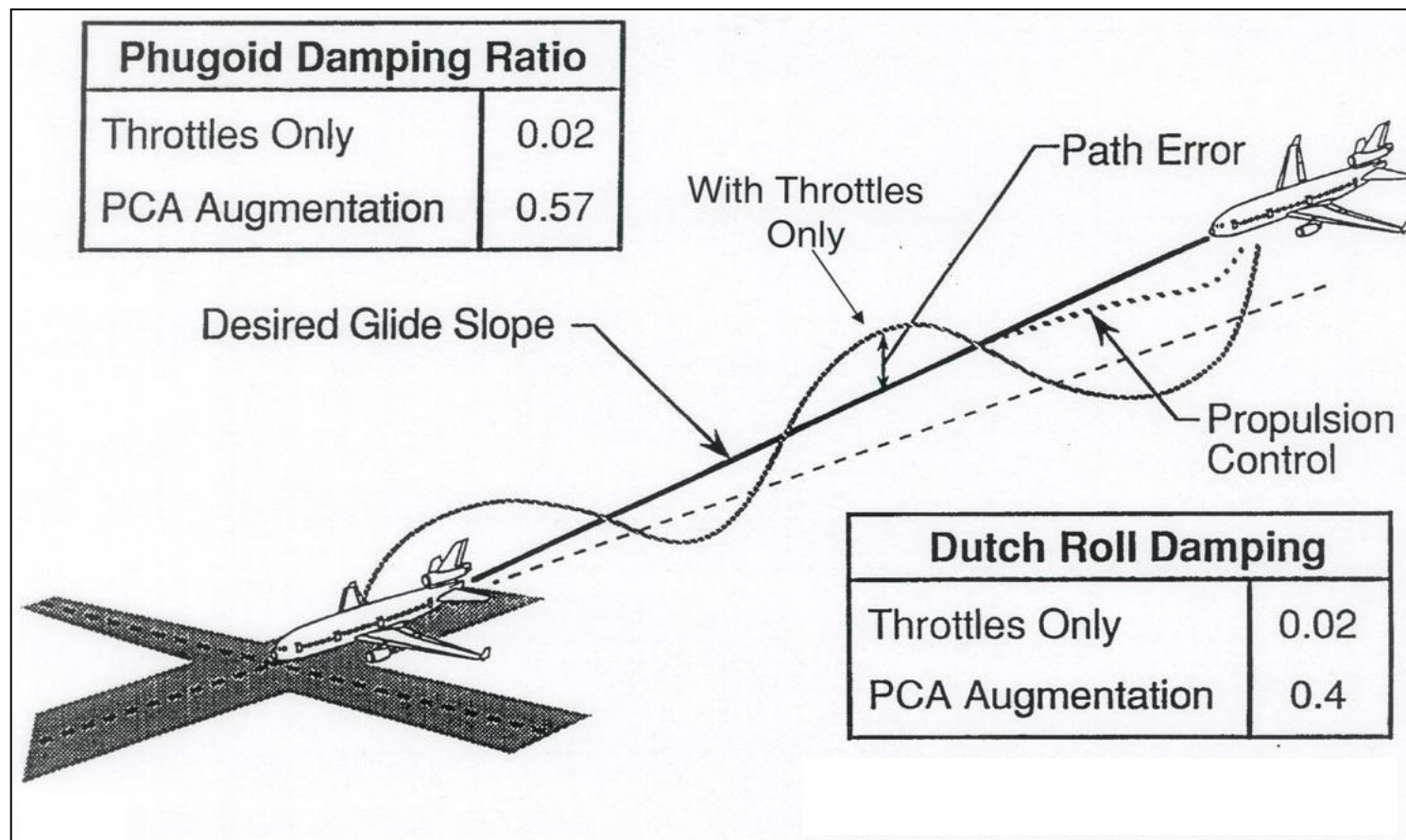


# Integrating Propulsion Control with Aircraft Systems



GRC Propulsion Control and Diagnostics Workshop  
11-12 November 2013

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## Flight Control using Propulsion Changes

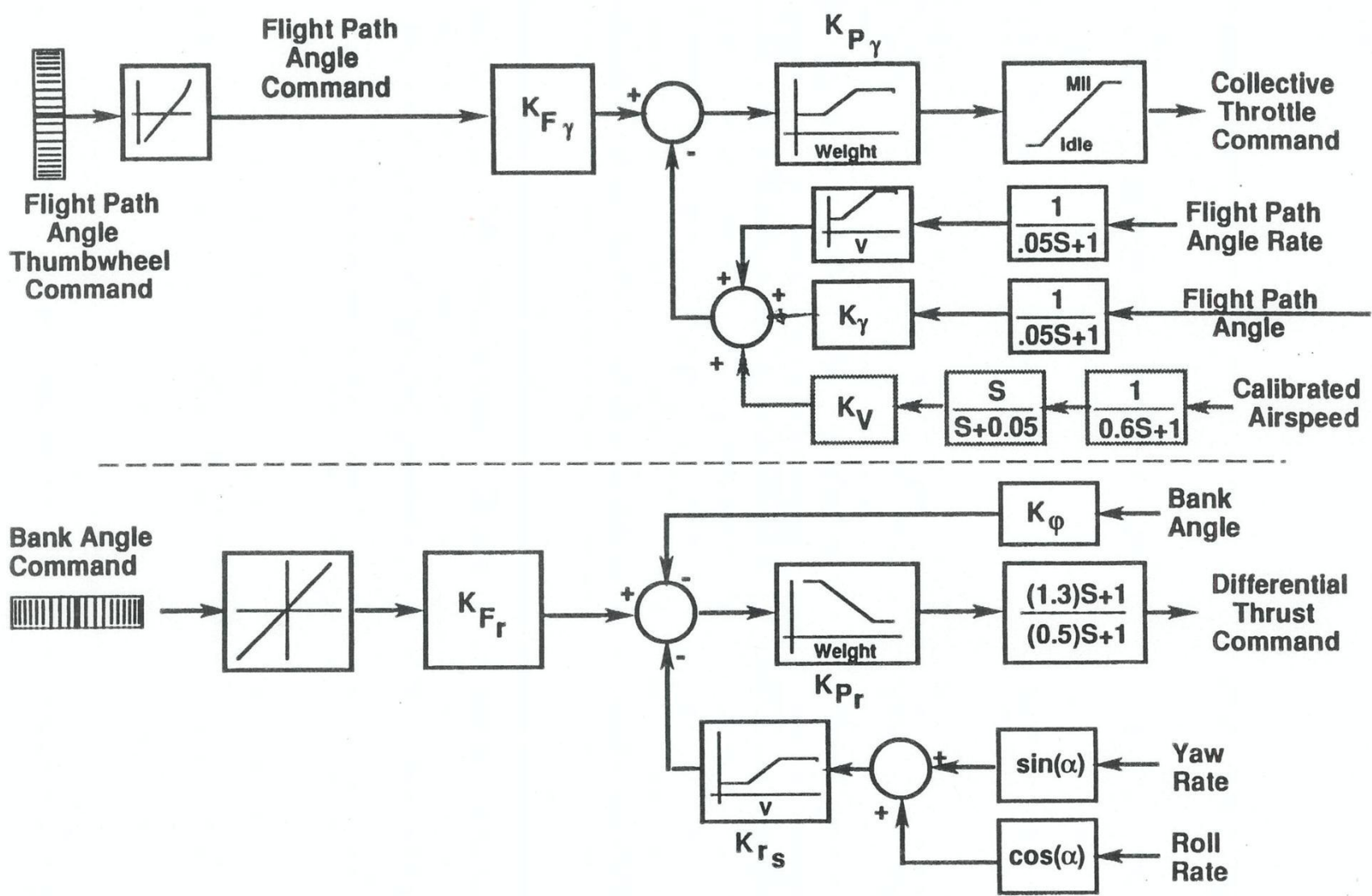
- Augment conventional flight control effectors with thrust effectors
- Enhance flight path control at extreme angle of attack and sideslip conditions
- Safety: Enables better performance for damaged flight control situations
- Certification for propulsion control more direct than conventional flight control effectors
- Flight path control for UAV aircraft
- Improved carrier landing for Navy tactical and UAV aircraft by integrating Approach Power Control with flight path control

# Integrated Propulsion / Flight Control Example: The PCA Program

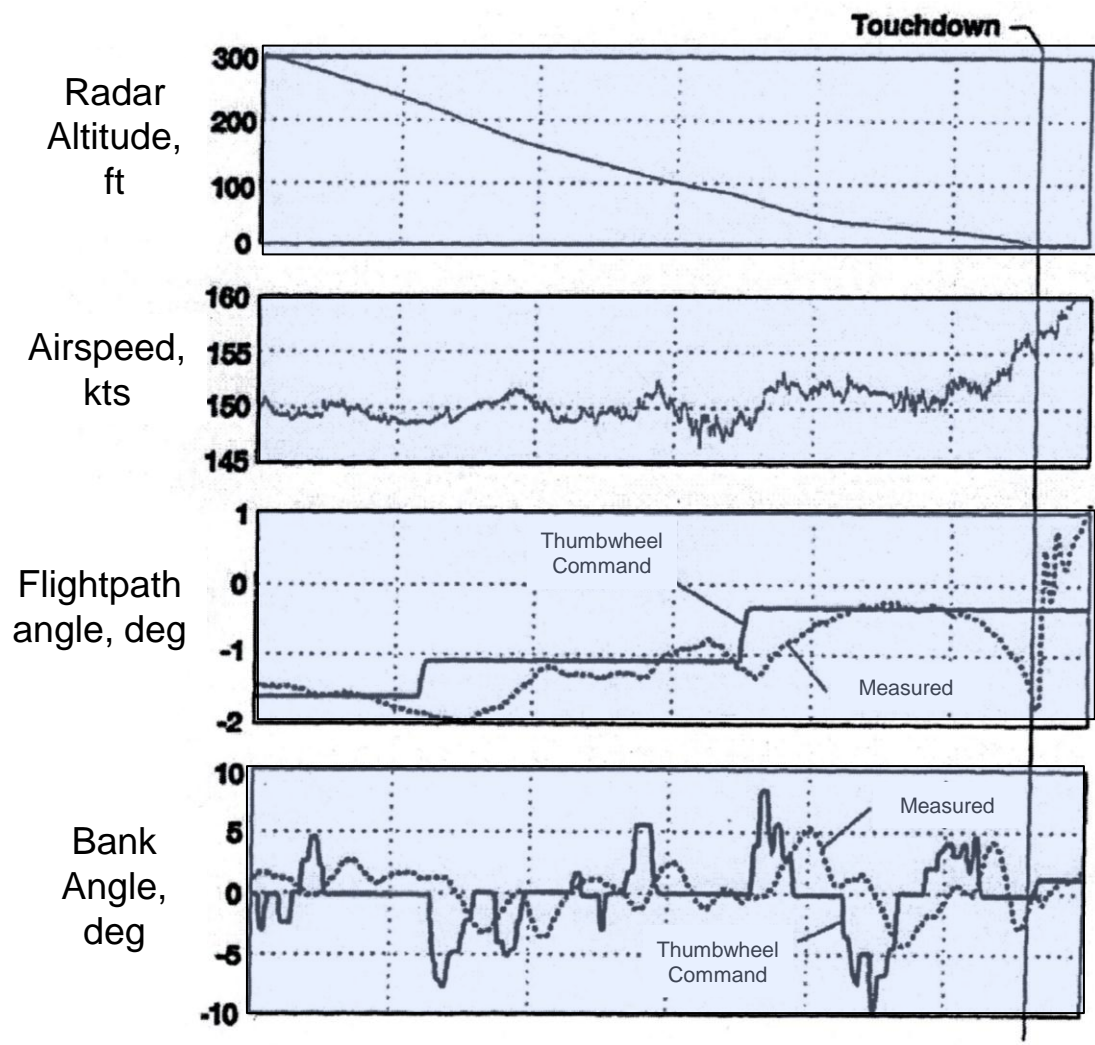


- **Program initiated after United Flight 262 lost all flight control and landed at Sioux City, Iowa**
  - Direct throttle control used, very difficult to control Phugoid and Dutch Roll Oscillations
- **Boeing developed a Propulsion Controlled Aircraft (PCA) flight mode for a NASA F-15 Test Aircraft**
  - Lead compensation applied in roll/yaw to increase thrust dynamic response
  - Thumbwheel controller for pitch and roll/yaw control instead of stick
  - Flight commands directly to engine controllers
  - No backdrive to throttles
  - Special HUD display to counter large lag in flight path response
- **Successful flight test results for navigation, letdown and landing with PCA**

# Example of Integrated Flight and Propulsion Control

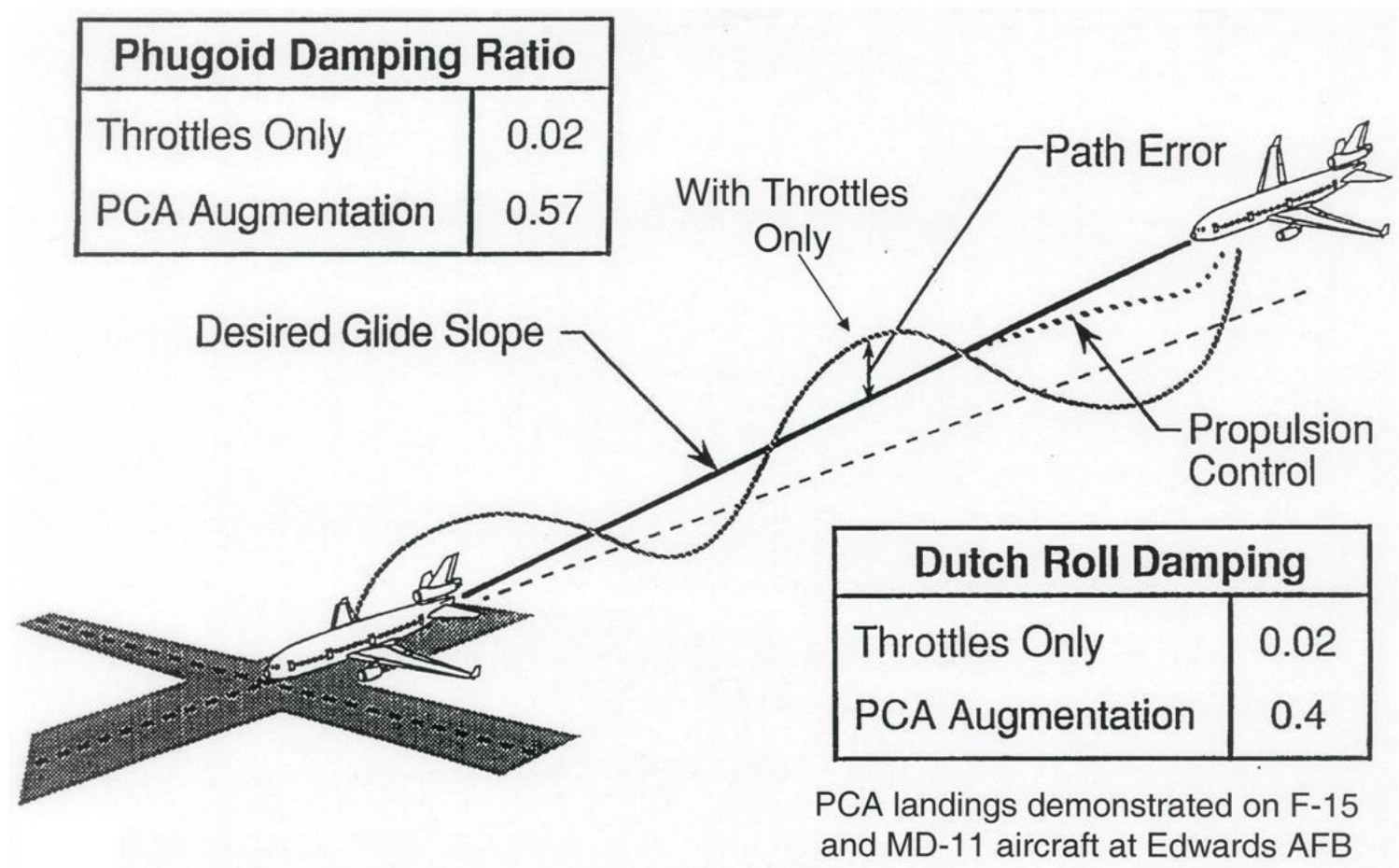


# F-15 First PCA Landing at EAFB



Landing  
Flown by  
Gordon Fullerton  
NASA F-15  
Test Pilot

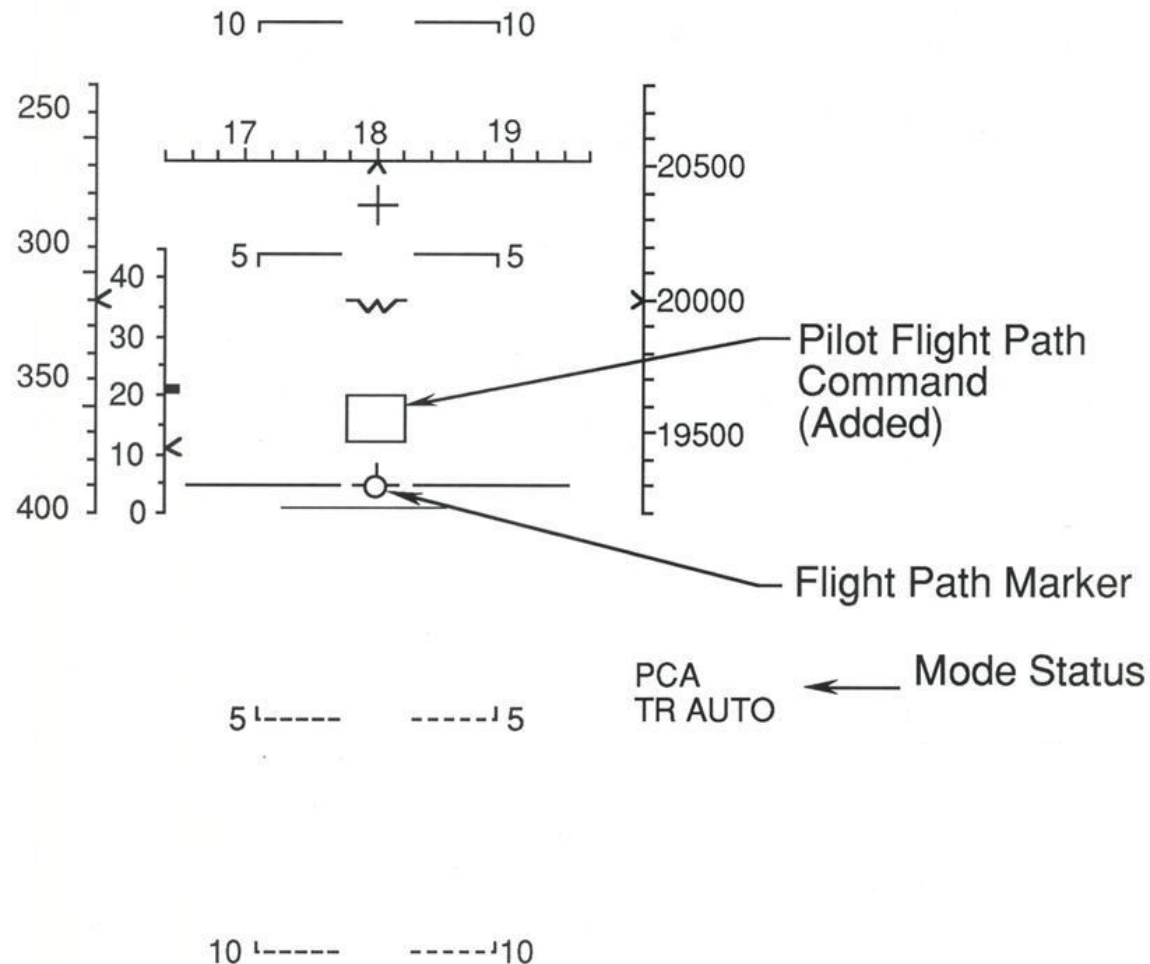
# Propulsion Control Provides Necessary Path Damping Improvement



# HUD Display for Slower PCA Response



Provides UAV Pilot with accurate prediction of flight path



- **Loss of Control**
  - Flight crew inattention can lead to exceeding aircraft flight envelope limits
  - Propulsion changes can limit pitch or roll excursions, provide safe maneuver boundary
  - After exceeding flight envelope limits, very difficult to recover
    - Engine thrust more effective than aileron or rudder control at extreme angle of attack
    - Must keep the engines operating at large angle of attack or sideslip conditions

# Roll Attitude Excursions and the Attitude at which Pilot Inputs were Initiated



Event	Airplane	Attitude when recovery attempt was initiated*	Attitude goes to	Roll rate **
Perm, Russia	737-500	30° L	>270° L; 65° ND	40° in 30 sec
Douala, Cameroon	737-800	34° R	115° R	2°/sec to 35°
Sulawesi, Indonesia	737-400	35° R	100° R; 60° ND	1°/sec to 35°
Sochi, Russia	A320	--		
Sharm el-Sheikh, Egypt	737-300	30° R	>60° R; ND	1-2°/sec to 40°
Irkutsk, Russia	Tu154 M	45° L	>70° L; ND	above threshold
Bahrain	A320	--		
Zurich, Switzerland	Saab 340B	no recovery		2-5°/sec
London	747-200	no recovery		
Hsin-Chu, Taiwan	Saab 340B	48° R; 8° ND	??	sub-threshold
Khabarovsk, Russia	Tu154	40° R	80° R	<1°/sec for 41 sec
Charlotte, USA	DC-9-31	--		
Mezhduretshensk, Russia	A310-300	50° R	90° R	initially 1°/sec
Guilin, China	737-300	50° R	155° R	1-2°/sec
Tucuti, Panama	737-200	insufficient data		
Toledo, USA	DC-8	60° L; ND	80° L; 30° ND	??
Belvidere, USA	Convair 580	no recovery		sub-threshold

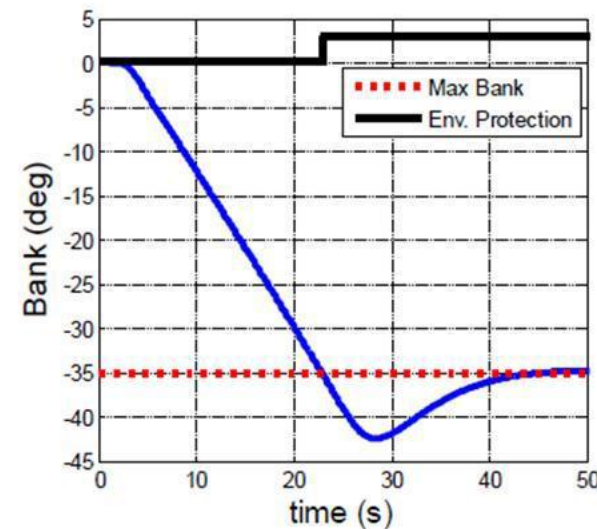
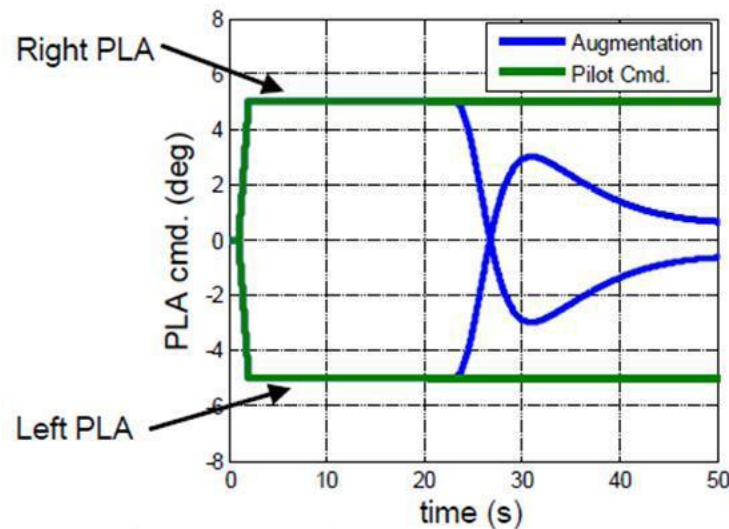
\* Approximations of attitude at a particular point

\*\* Threshold for perception of roll rate  $\approx 2^\circ/\text{sec}$

# Thrust Augmentation Limits and Aircraft Bank Angle



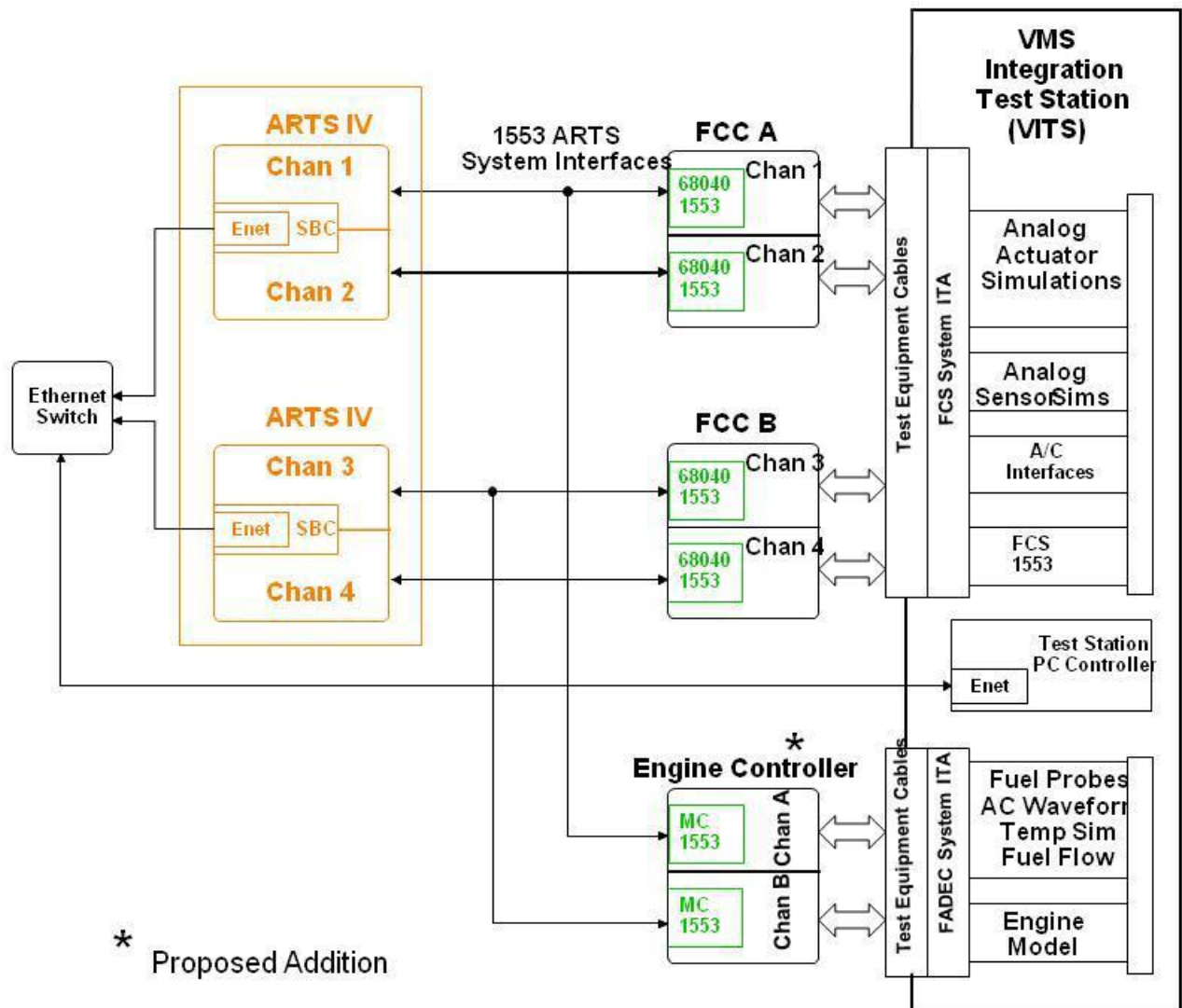
- **Bank Angle Limiting Simulation Scenario:**
- Throttle split of 10 deg. differential induces unwanted bank excursion.
- Bank angle increases
- When max bank angle is exceeded, thrust augmentation drives bank angle back to the boundary limit value



## **Initial Step: Integrate the function of flight control and engine control**

- Link or combine the flight and propulsion controllers
- Enhances propulsion performance
  - Modes for takeoff, cruise, landing
  - Better schedules for fuel economy
  - Better control of emissions
- Keep engine operating at extreme inlet airflow angles or obstructed inlet due to ice, bird strike
- Improves engine health monitoring, diagnostics
- Enables reconfigurable control for failed engine components

# F/A-18 Research Flight Control System with Engine Controller Research Capability



# Summary: Integrating Propulsion Control with Aircraft Systems



- **Integration benefits flight and propulsion control**
- **Enables optimum engine operating modes**
- **More choices for alternate paths or components during flight with failed or marginal components**
- **Enhances Vehicle Health Management**
- **Can result in increased fuel efficiency, engine life**
- **Advances Environmental Control for better cooling, power distribution**
- **Future (N+3) aircraft with lighter weight, Distributed Electric Propulsion, wing shaping for drag reduction**